TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 623

MAXIMUM FORCES APPLIED BY PILOTS TO WHEEL-TYPE CONTROLS

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SUMMARY

Measurements were made of the maximum push, pull, and tangential forces that could be applied to airplane wheel-type controls for a wide range of fore-and-aft positions of the wheel. The measurements were conducted with several sizes of wheels and several heights of the center of the wheel above the seat. Various one- and two-hand grips with pilots both secure and free were studied for each of the two pilots used in the investigation.

INTRODUCTION

During 1934, measurements were made at Langley Field of the maximum fore-and-aft and lateral forces a pilot could exert on a control stick. These results are published in reference 1. Because of interest in the forces on wheel-type controls, the measurements reported in reference 1 have been extended to include the forces, both fore-and-aft and tangential, that a pilot can exert on wheel-type controls.

APPARATUS

The apparatus used for making the measurements consisted of a model cockpit with pilot's seat, control wheel, and rudder bar. The forces were indicated by an Ames strain gage and a flexible beam, as described in reference 1, with the exception that a special fitting was designed to give both push and pull and tangential forces as applied at the rim of the wheel. This apparatus is accurate to ±3 pounds. Figure 1 is a photograph of the set-up for measuring push and pull forces, showing the belts used for securing the pilot in the seat. Figure 2 is a photograph of the set-up for measuring tangential forces; it also shows the belts used for securing the pilot in the seat. Figure 3 is a photograph showing details of the set-up for measuring tangential forces.

Four wheel sizes were used, as follows:

12-inch wheel - outside diameter 12-3/4 inches.

14-inch wheel - outside diameter 14-3/4 inches.

16-inch wheel - outside diameter 16-3/4 inches.

18-inch wheel - outside diameter 18-3/4 inches.

(Diameter of wheel given on charts is median diameter of rim. Rim is of plywood 3/4-inch thick and 1-1/2 inches deep.)

The two pilots whose physical characteristics are given in table I(a) were used in the investigation.

TESTS

The tests were conducted with the cockpit attitude normal or level and with the pilot sitting on a parachute, placed in a bucket-type pilot's seat. The pilot's feet were placed comfortably upon the rudder bar, which was free to rotate but was normally held in a neutral position. No other restriction was placed upon the use made of the rudder bar while applying forces to the wheel. For all test conditions, measurements were made for a range of fore-and-aft positions of the wheel.

For most of the tests the pilot was secured by two belts, an ordinary safety belt and a chest belt or strap, as in the earlier control-stick tests (reference 1). The acrobatic shoulder harness used in the earlier tests was not worn because it did not restrain or affect the pilot's reach in the normal attitude of the cockpit when the chest strap was used. Additional tests were made with the belts detached to obtain a comparison of forces applied while secure and free. No tests were made with the ordinary safety belt alone because this belt has very little, if any, effect on forces applied by the pilot in any normal-flight condition.

Measurement of push and pull forces with several sizes of wheel were made with the center of the wheels 16 inches above the seat. With the 12-inch-diameter wheel, measurements were also made with the wheel center 10 inches above the seat to determine the effect of the vertical position of the wheel. The schematic drawing in table I(b) shows the limits of the wheel position for the tests.

Tangential forces applied at the wheel rim were completely investigated with the wheels at a height of 14 inches. The 12-inch wheel was also placed at heights of 10 inches and 18 inches to determine the effect of height on tangential forces.

The grip used in all tests, except the tests dealing with the position of the hand or hands upon the wheel (for tangential force only), was a normal grip with a hand on each side of the wheel. For the tests dealing with the effect of position of the hand or hands upon the wheel and with variation of force applied as the wheel was turned, the 12-inch wheel was gripped with both hands and with one hand in several positions. For one-hand grips only the right hand was used; i.e., one hand on the top of the wheel (arm along wheel rim) or one hand on the side of the wheel.

In order to find the effect of the turning of the wheel upon the maximum tangential force, the wheel was gripped as though, with grip normal, the wheel were turned through 90° and force applied in the direction of turn (hands on top and bottom of wheel). The other position tested with a two-hand grip was with both hands on the top of the wheel.

RESULTS AND DISCUSSION

The results of the measurements to determine the maximum forces that can be applied to a wheel control under varying conditions of wheel size, wheel height, and longitudinal position of the wheel in the cockpit are presented in figures 4 to 19. In all the figures the maximum forces are plotted against longitudinal position of the wheel.

Push and pull forces.- In figures 4 and 5 are shown the push and pull forces obtained with the pilot secure and free. It will be noted that the tendency is for the push forces to peak with the wheel in a position about 24 inches from the back of the seat. It is also shown that the pilot can exert a greater pull force when in the secure position.

The effect of wheel diameter is shown in figures 6 and 7. In general, the forces for the pilot secure tend to be greater with the 16-inch wheel for both push and pull conditions. It is interesting to note that for the push forces the optimum wheel position is about 24 inches from seat, while pull forces increase steadily with the distance of the wheel from the seat.

The effect of wheel height above the seat (figs. 8 and 9) shows a marked increase in push and pull forces with the wheel in the higher position over a large part of the range. For pull, however, the forces follow more closely for the two height conditions.

Tangential forces.- The variation of tangential force with wheel diameter shows that larger forces are obtained with the smaller wheel diameters for both clockwise and counterclockwise rotation (figs. 10 and 11). It will be noted that minimum forces are obtained with the wheel in the extreme forward position.

The tangential forces obtained with pilot secure and pilot free (figs. 12 and 13) are approximately equal with the wheel in the rearmost position but, as the wheel is moved forward, there is a definite decrease in the forces applied by the pilot in the secure position. This decrease is due chiefly to the fact that, as the wheel is moved away from the pilot, it becomes necessary for him to work with arms more extended, thereby cutting down on his mechanical leverage.

The effect of variation of wheel height above the seat is shown in figures 14 and 15. The general trend of the forces as shown would indicate that the high wheel position is slightly favorable.

The results of various two-hand positions are shown in figures 16 and 17 and represent a few of the combinations of positions that can be obtained for normal-flight use. The position of both hands on the sides of the wheel is considered to be the most common for normal flying, while both hands on top of the wheel is probably used as an alternate position. The quarter-turn of the wheel position (hands on top and bottom) was investigated principally to show the forces that can be applied when moving the wheel through the larger displacements.

Figures 18 and 19 show the forces obtainable through a single-hand effort (right hand) on the wheel. It is interesting to note that for the clockwise rotation the greater force can be exerted by one hand, as against the two-hand position on top of the wheel. (See figs. 16 and 17.) The reason for this difference is believed to be due to the more favorable position the pilot can assume in the one-hand position.

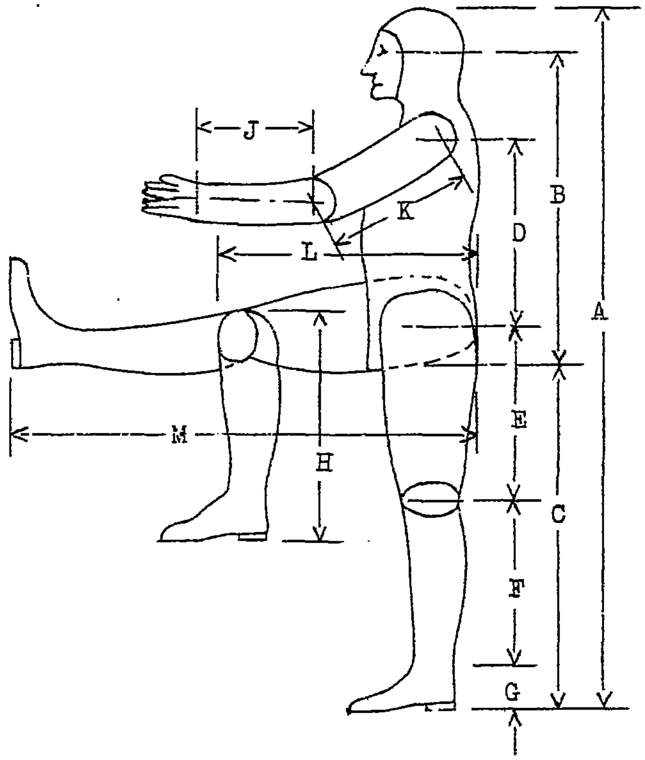
Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 11, 1937.

REFERENCES

1. Gough, M. N., and Beard, A. P.: Limitations of the Pilot in Applying Forces to Airplane Controls. T.N. No. 550, N.A.C.A., 1936.

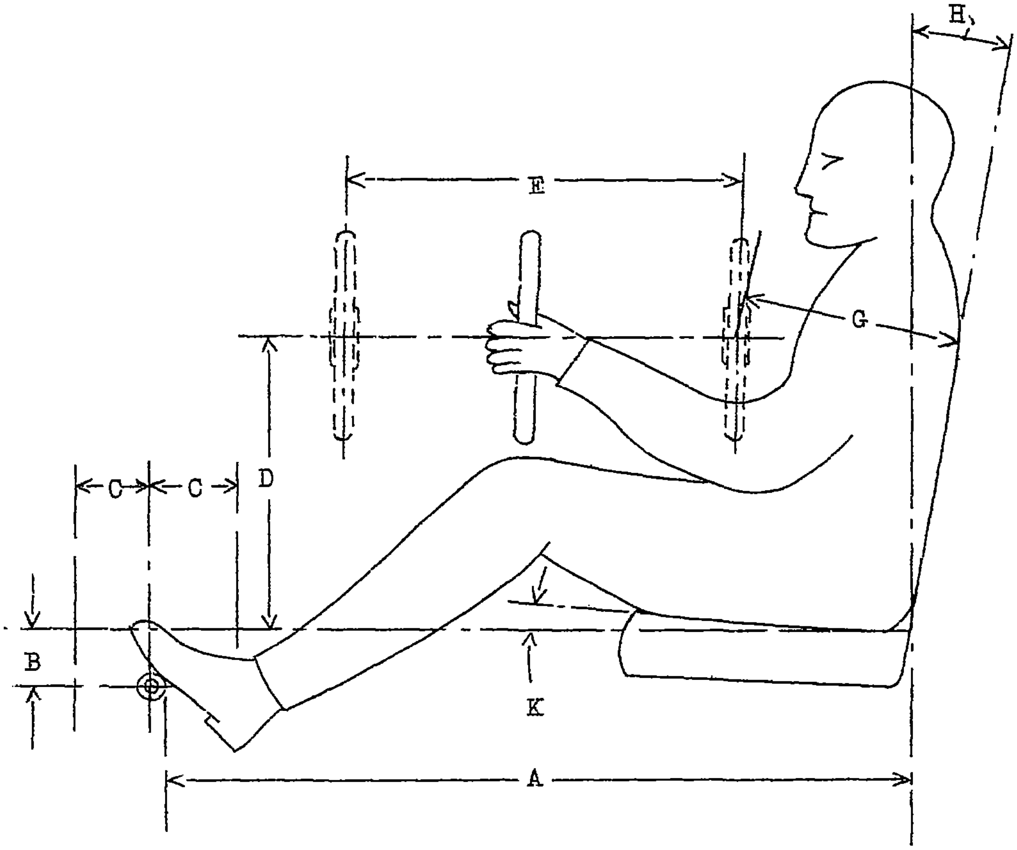
2. Matériel Division, U.S. Army Air Corps: Dimensions of Average Pilot. Handbook of Instructions for Airplane Designers, vol. I, seventh edition, 1932, fig. 163, p. 325.

TABLE I(a). The Physical Dimensions of the Two Pilots



Dimension	Average pilot (reference 2) (in.)	Pilot A (in.)	Pilot B (in.)
A	68.20	66.5	66.0
B	30.70	30.5	31.3
C	33.28	33.4	33.0
D	17.84	17.5	19.0
E	17.12	16.5	14.8
F	16.40	16.2	16.0
G	4.12	4.4	4.5
H	22.00	21.5	21.5
J	10.48	10.1	9.0
K	13.12	9.8	10.0
L	23.85	23.3	22.5
M	42.80	41.3	41.0
Distance between finger tips with arms spread (in.)		67.0	68.0
Weight without flying gear (lb.)		145.0	165.0

TABLE I(b). Arrangement of Cockpit Controls



Dimension	U.S. Navy specification (in.)	U.S. Army Air Corps specification (in.)	Average of 7 N.A.C.A. airplanes (military and commercial)(in.)	Cockpit model used in tests (in.)
A	35 to 41	35-3/8 to 39-3/8	35 to 39	33-1/2
B	6 to 10	2-1/4 to 10-3/4	3 to 5	6
C	3 to 5	3-1/4	3 to 4	-
D	15 to 17	12 to 19-1/2	14 to 22	10 to 18
E	18 to 22	18	14 to 19	18
G	12 minimum	16-5/8	9 to 13	12
H	8° to 10°	13-1/2°	6° to 10°	14°
K	3°	-	5° to 12°	10°
Lateral distance, center to center, of rudder pedals		16-1/4	12 to 21	20

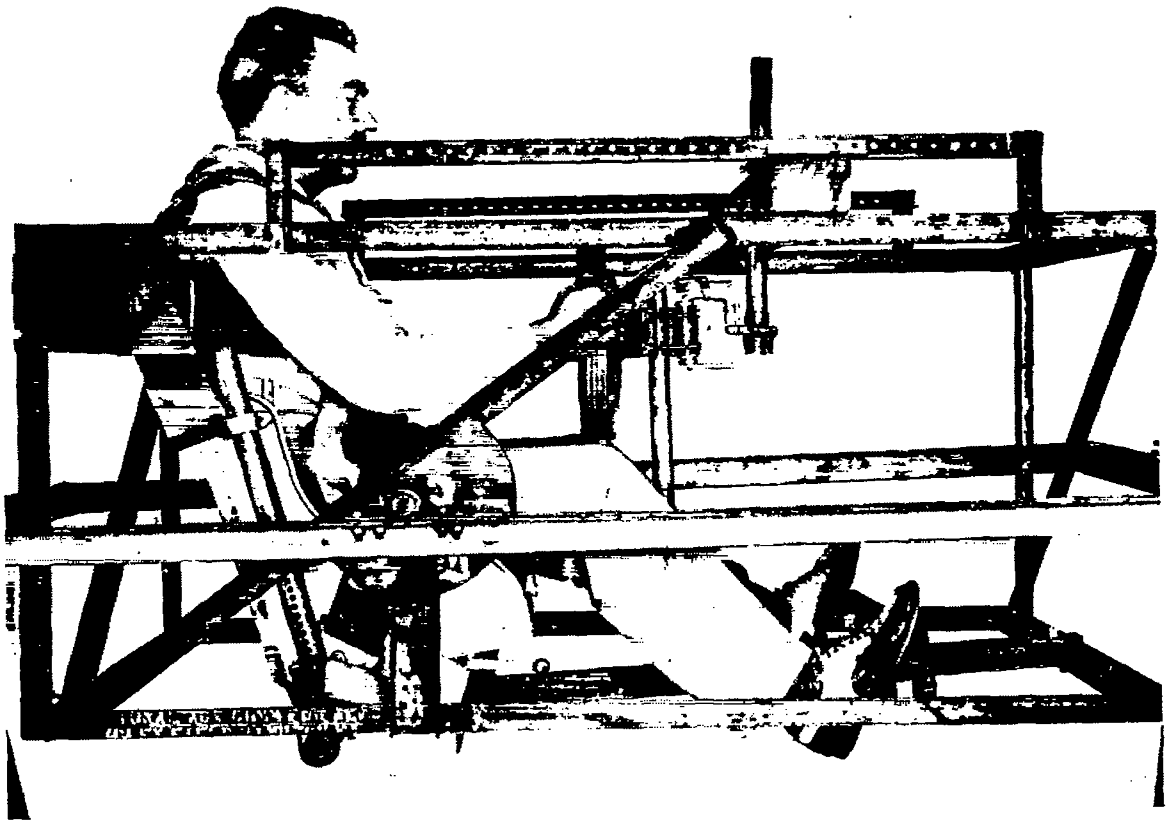


Figure 1.- Set-up for measuring push and pull forces.

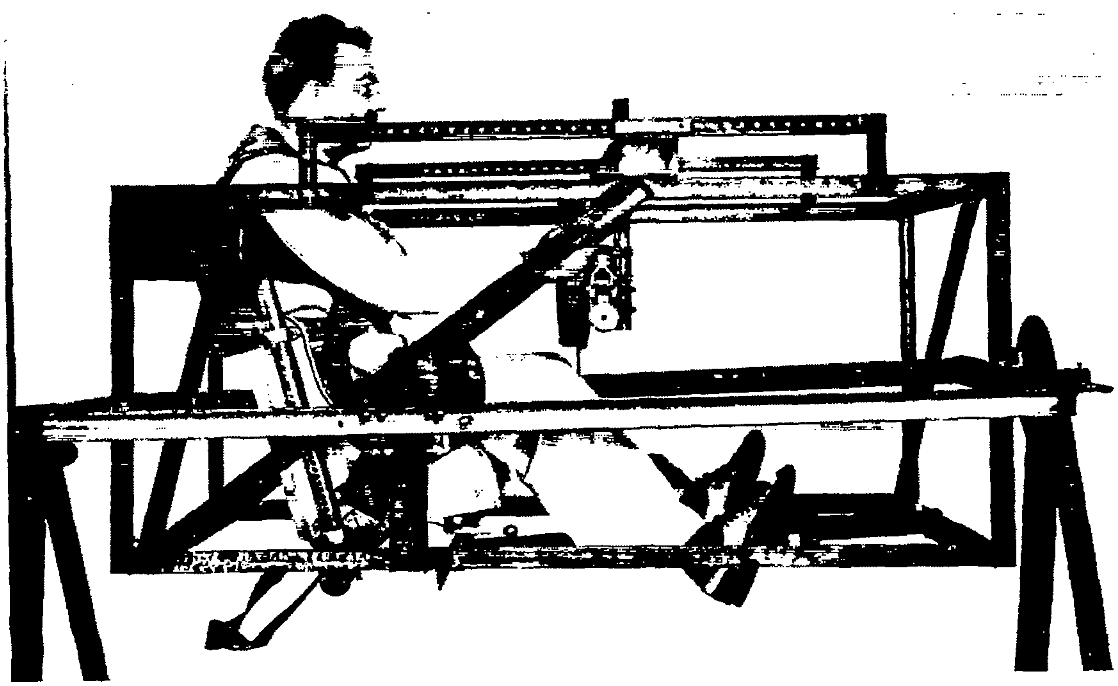


Figure 2.- Set-up for measuring tangential forces.

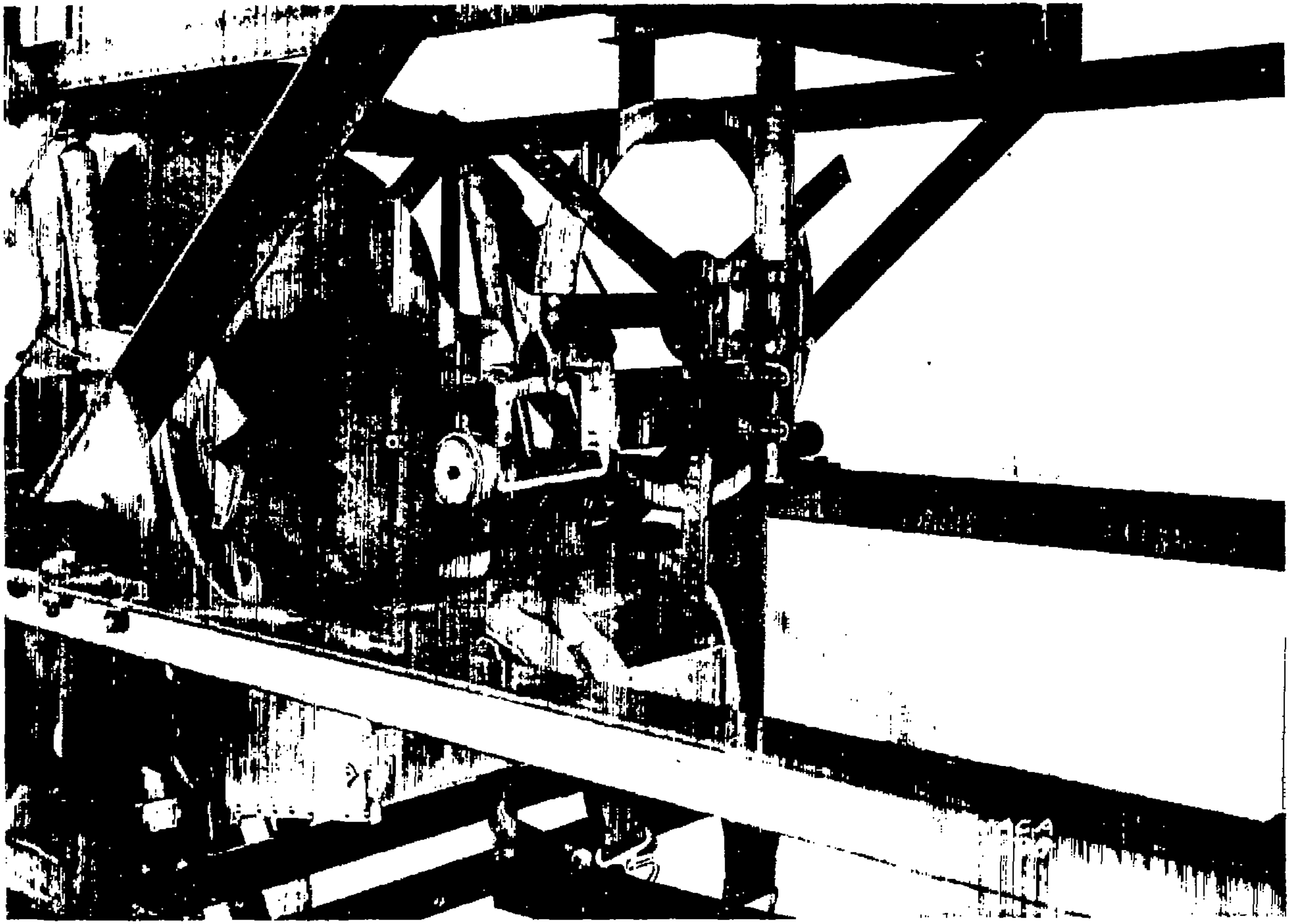


Figure 3.- Detailed view of set-up for measuring tangential forces.

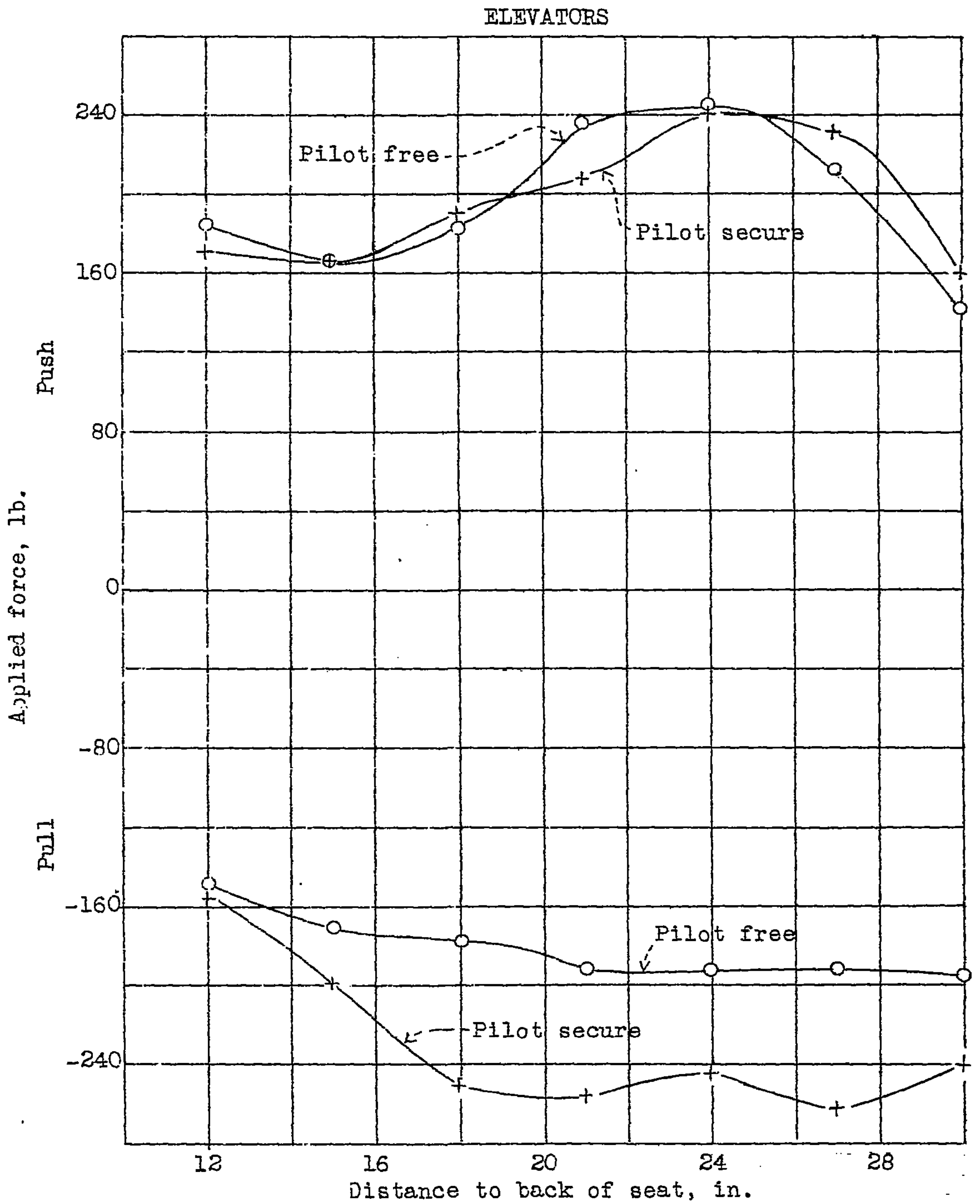


Figure 4.- Variation of push and pull forces with pilot free and pilot secure, 12 inch wheel, center of wheel 16 inches above seat, grip normal, pilot A.

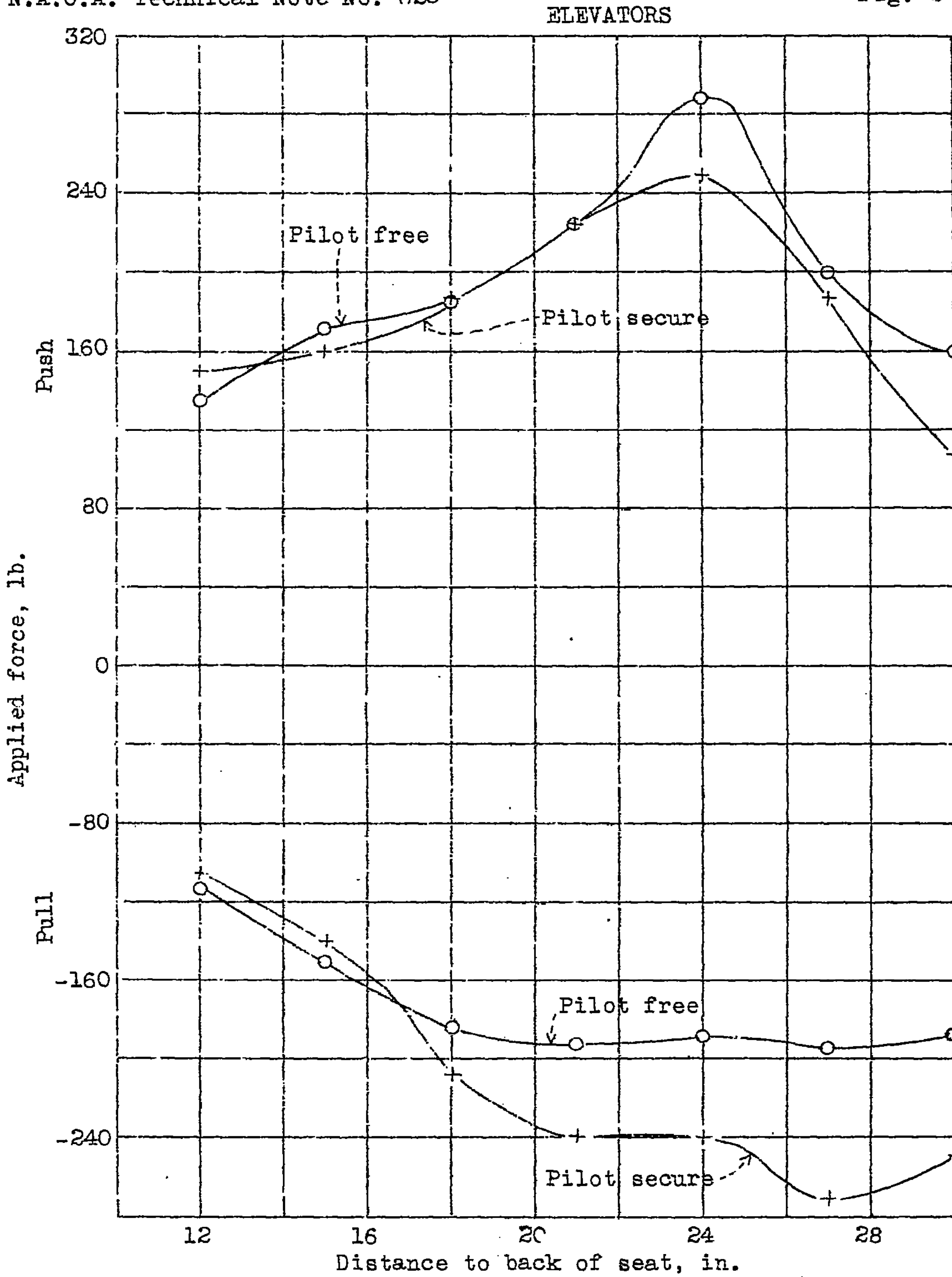


Figure 5.- Variation of push and pull forces with pilot free and pilot secure, 12 inch wheel, center of wheel 16 inches above seat, grip normal, pilot B.

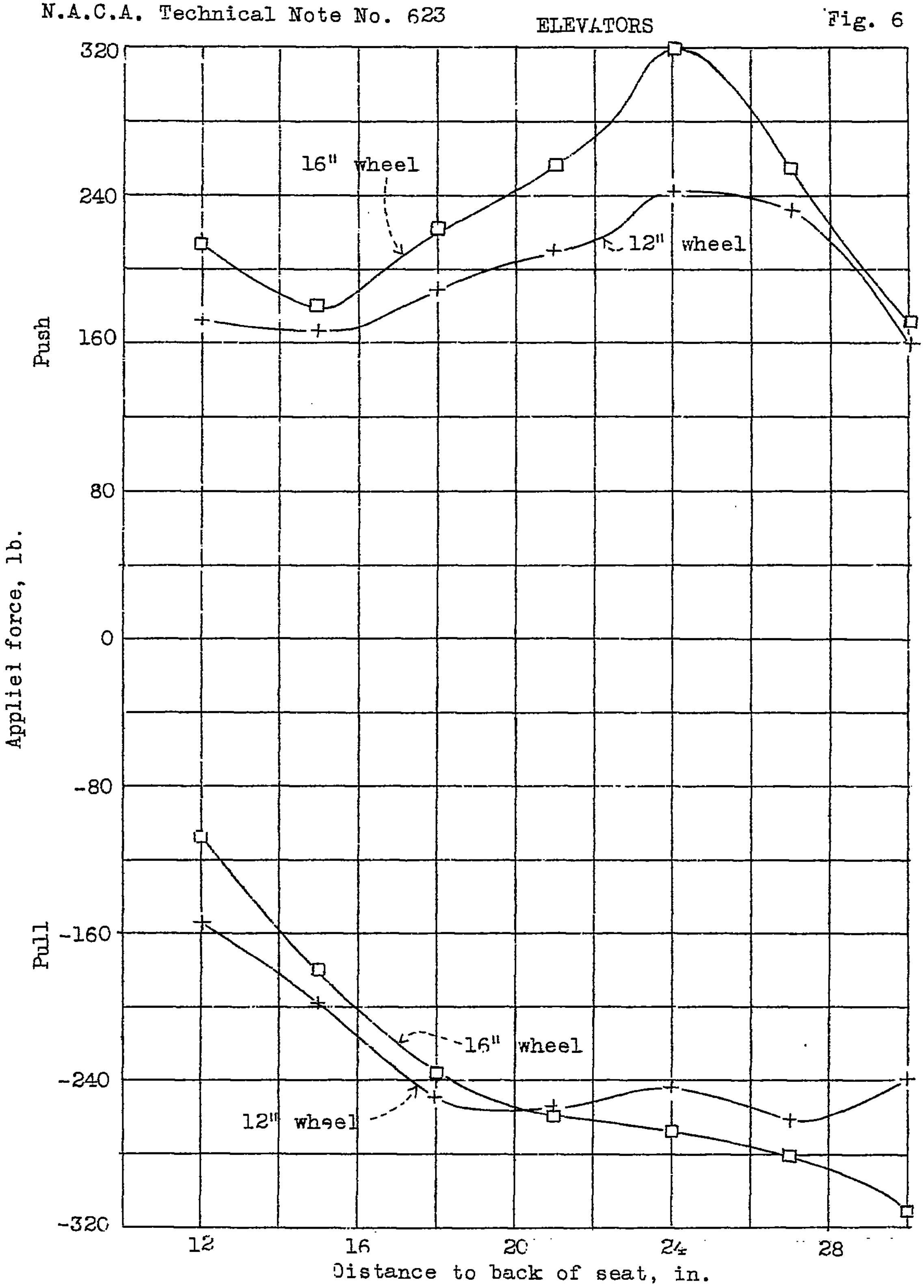


Figure 6.- Variation of push and pull forces with wheel diameter, center of wheel 16 inches above seat, pilot secure, grip normal, pilot A.

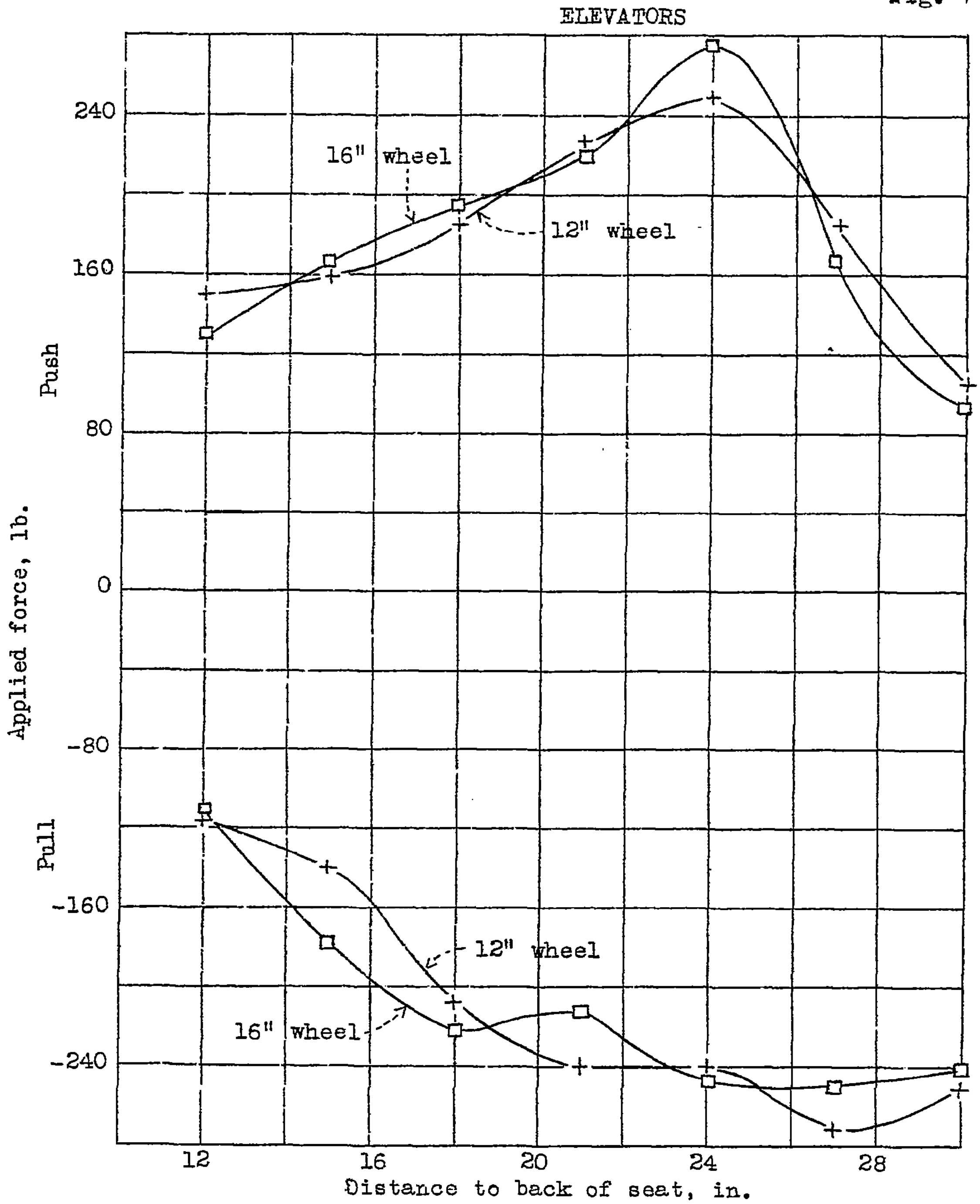


Figure 7.- Variation of push and pull forces with wheel diameter, center of wheel 16 inches above seat, pilot secure, grip normal, pilot B.

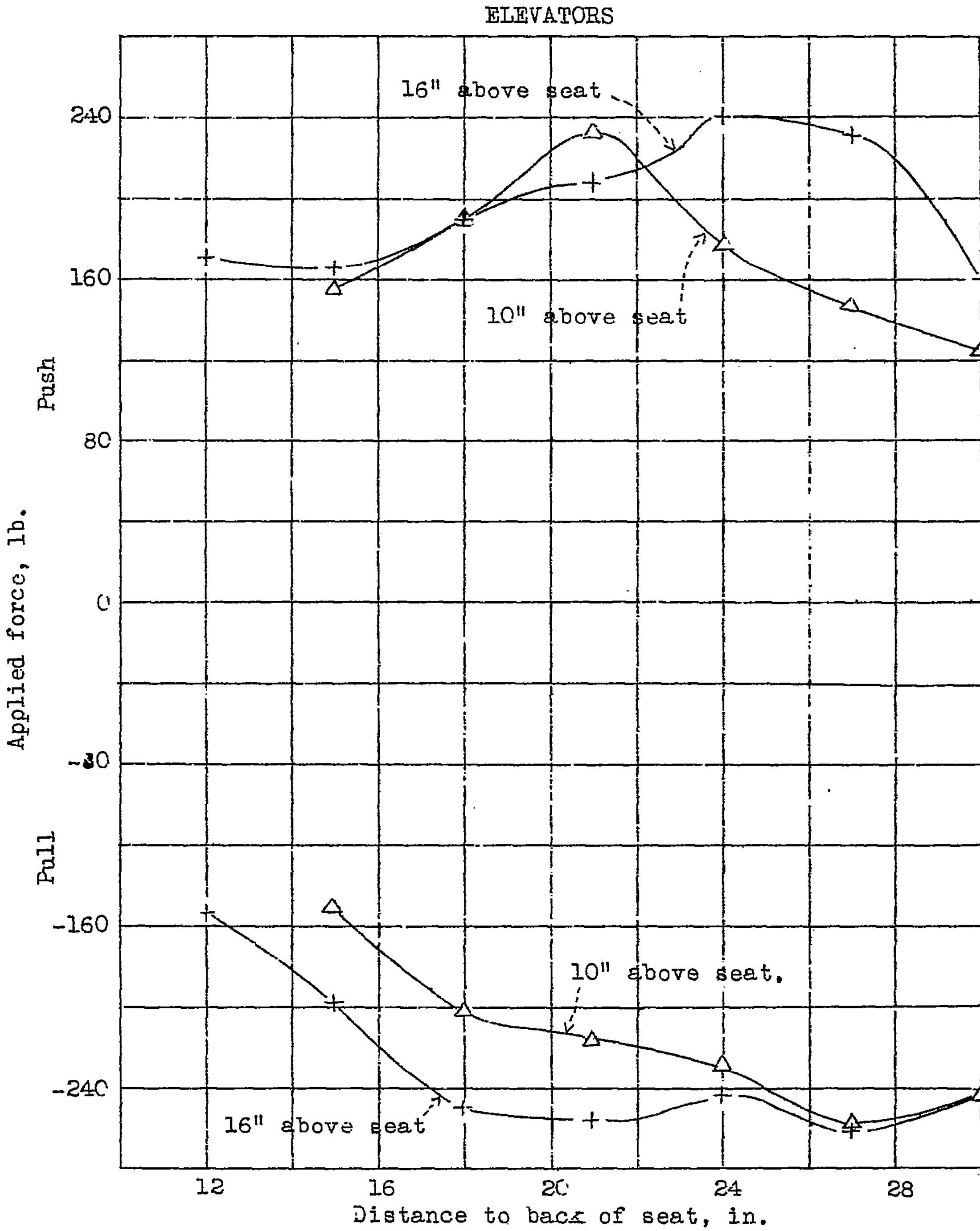


Figure 8.- Variation of push and pull forces with height of center of wheel above seat, 12 inch wheel, grip normal, pilot secure, pilot A.

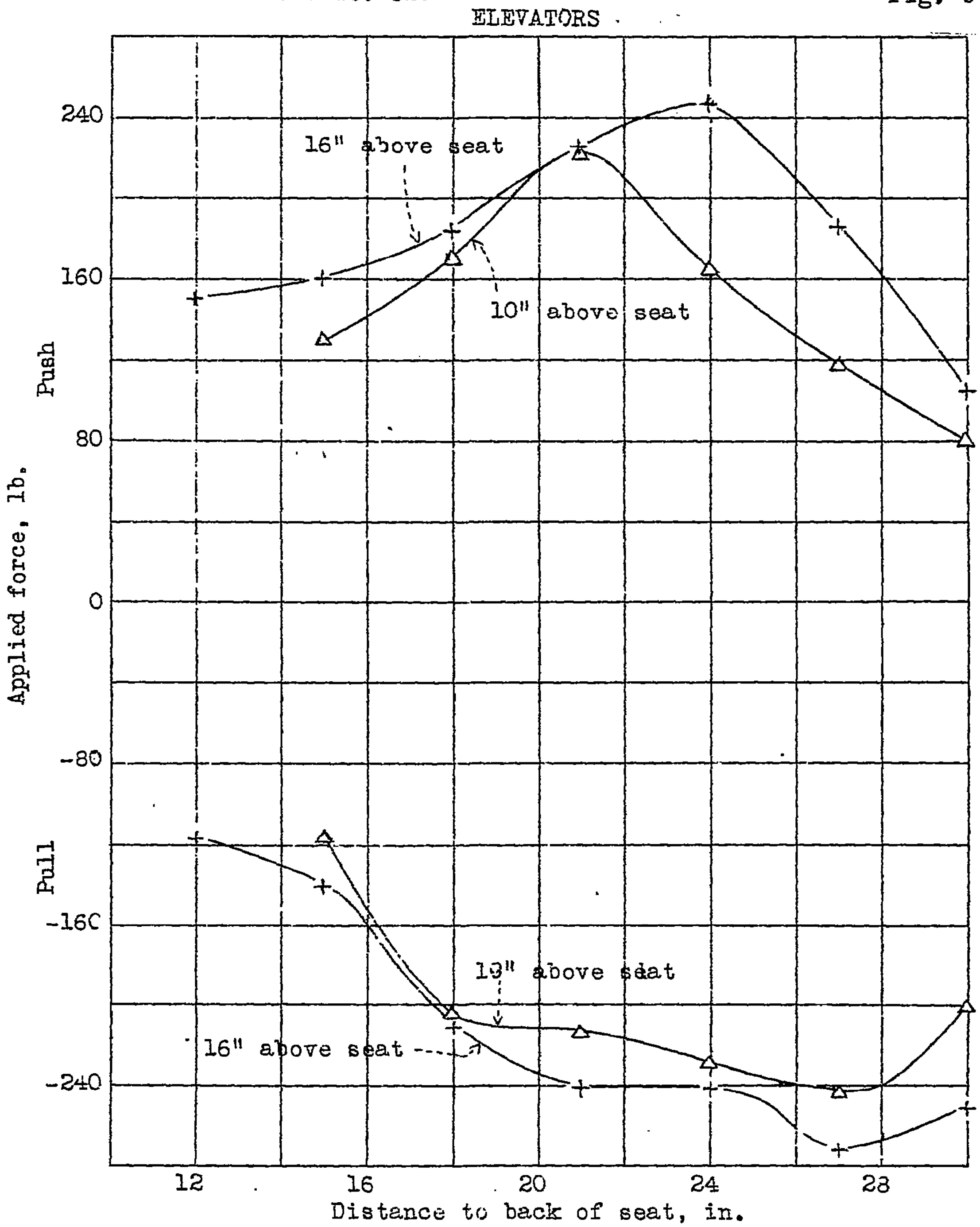


Figure 9.- Variation of push and pull forces with height of center of wheel above seat, 12 inch wheel, grip normal, pilot secure, pilot B.

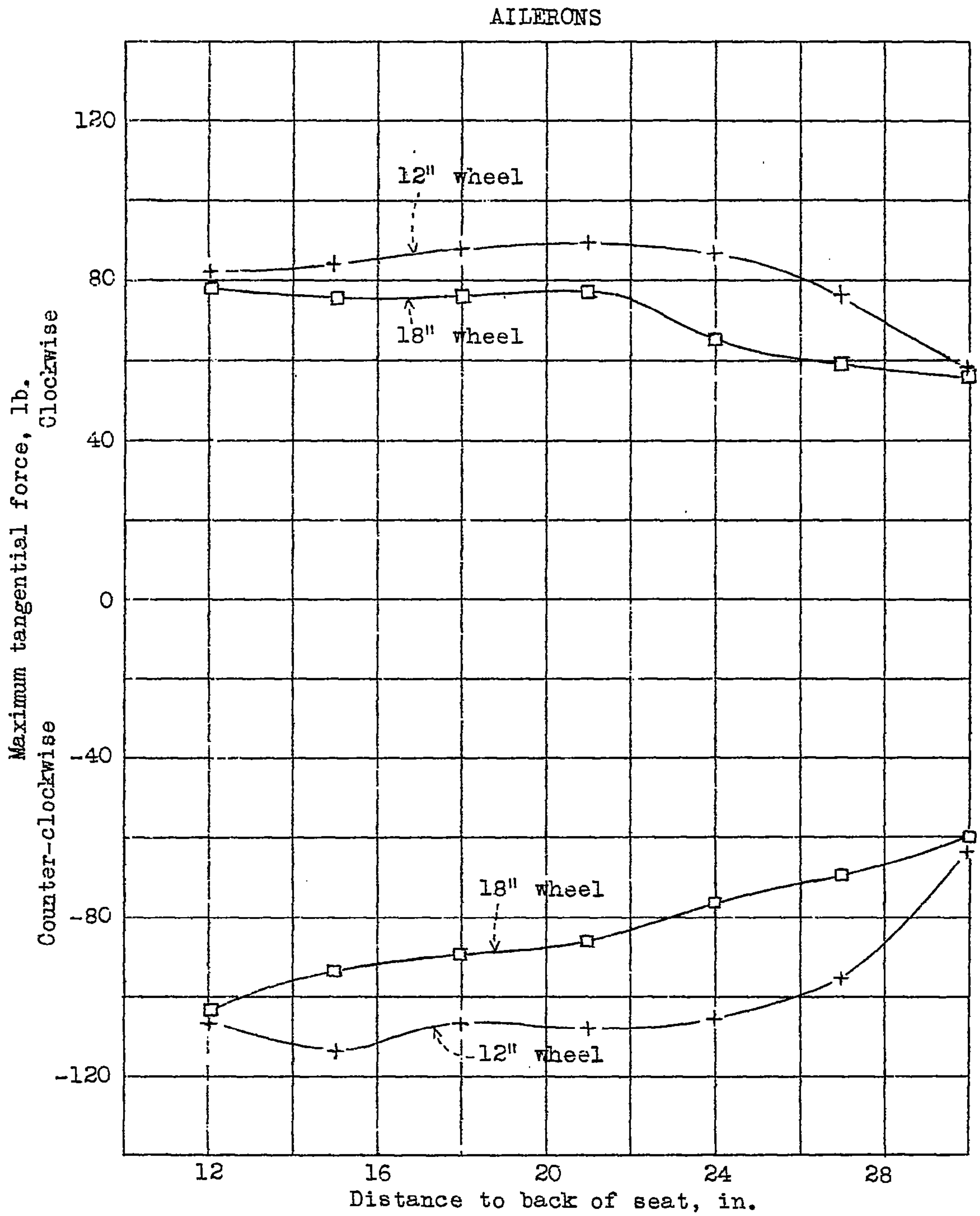


Figure 10.- Variation of tangential force with wheel diameter, 12 and 18 inch wheels, center of wheel 14 inches above seat, pilot secure, grip normal, pilot A.

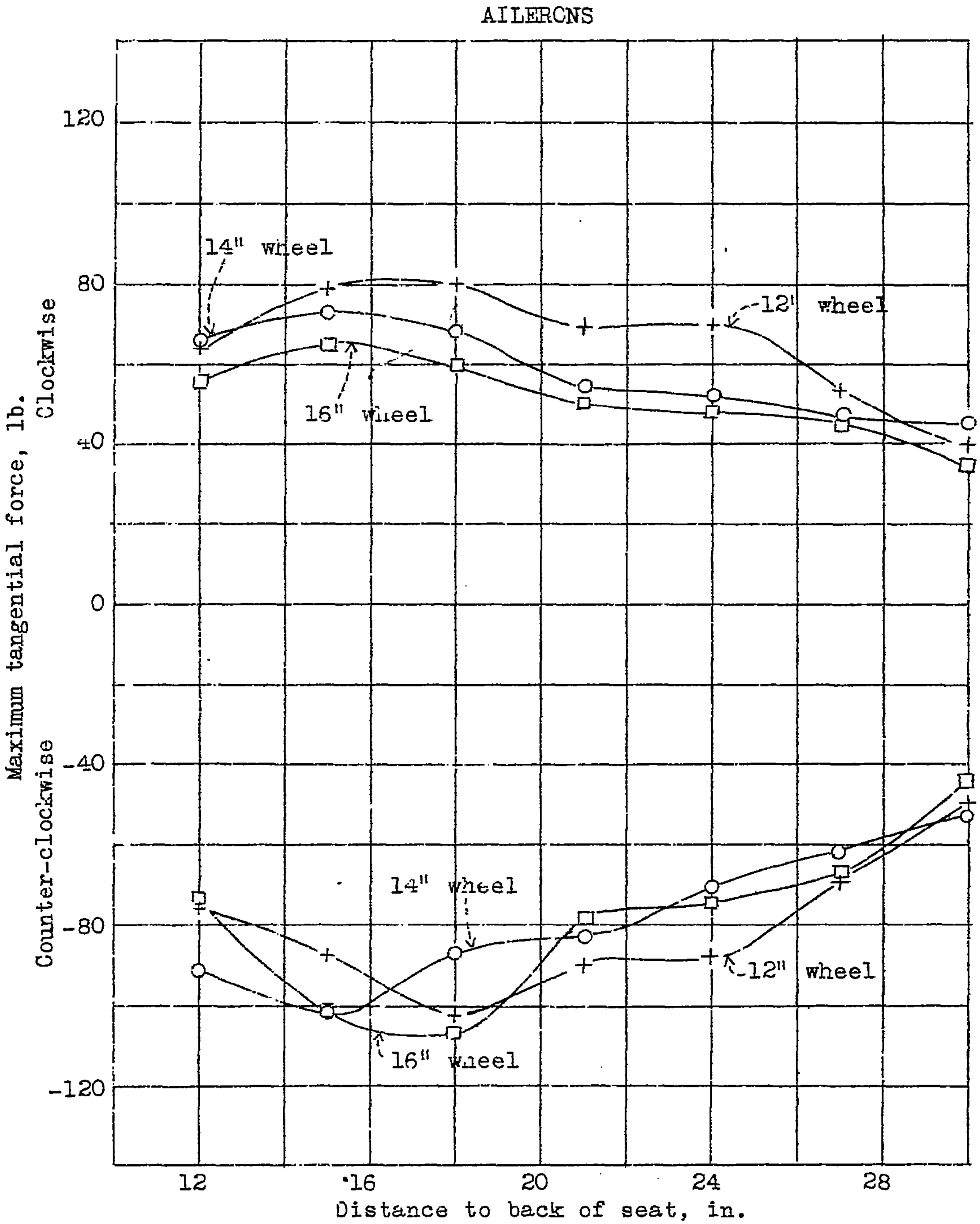


Figure 11.- Variation of tangential force with wheel diameter, 12, 14 and 16 inch wheels, center of wheel 14 inches above seat, pilot secure, grip normal, pilot B.

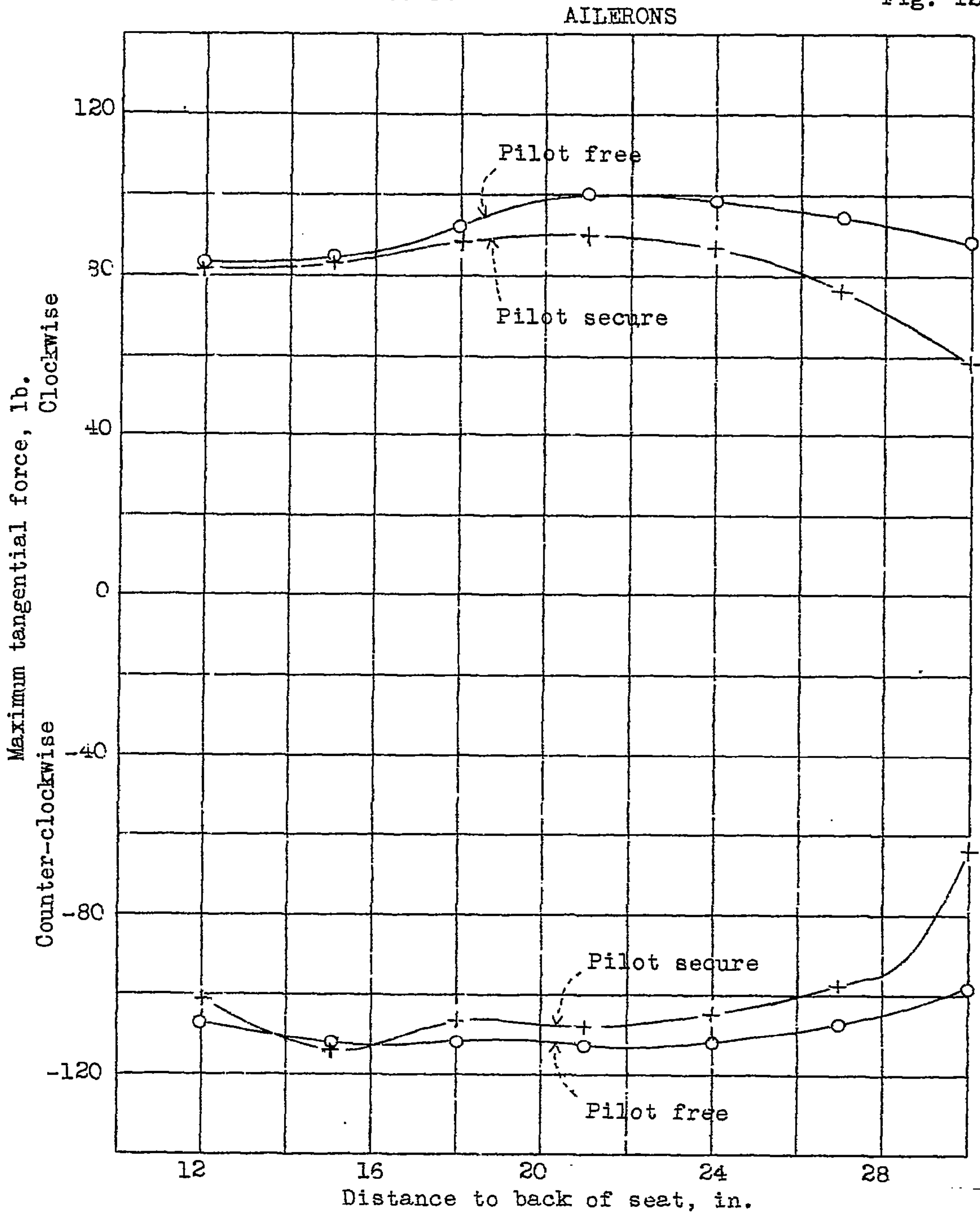


Figure 12.- Variation of tangential force with pilot free and pilot secure, 12 inch wheel, center of wheel 14 inches above seat, grip normal, pilot A.

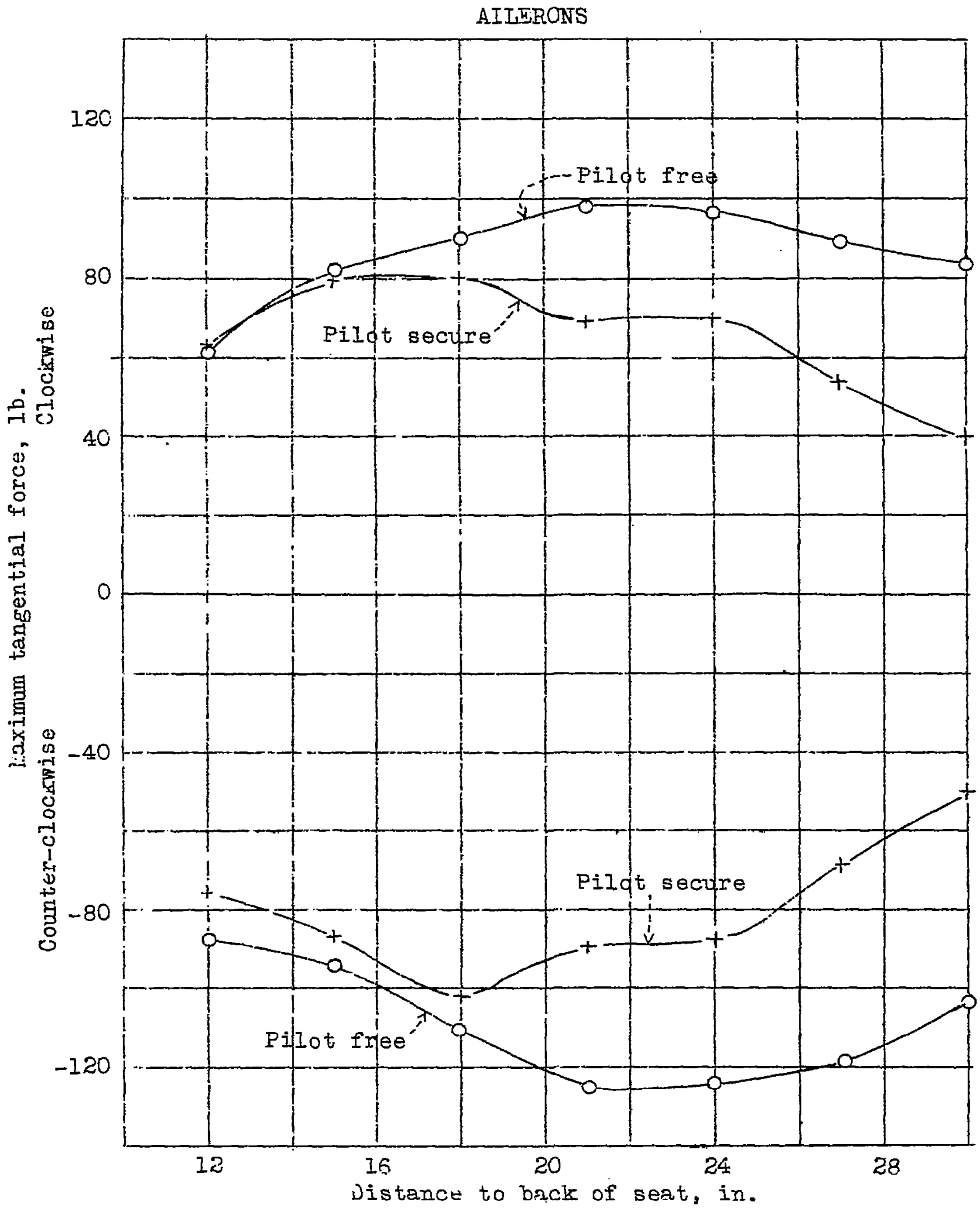


Figure 13.- Variation of tangential force with pilot free and pilot secure, 12 inch wheel, center of wheel 14 inches above seat, pilot B.

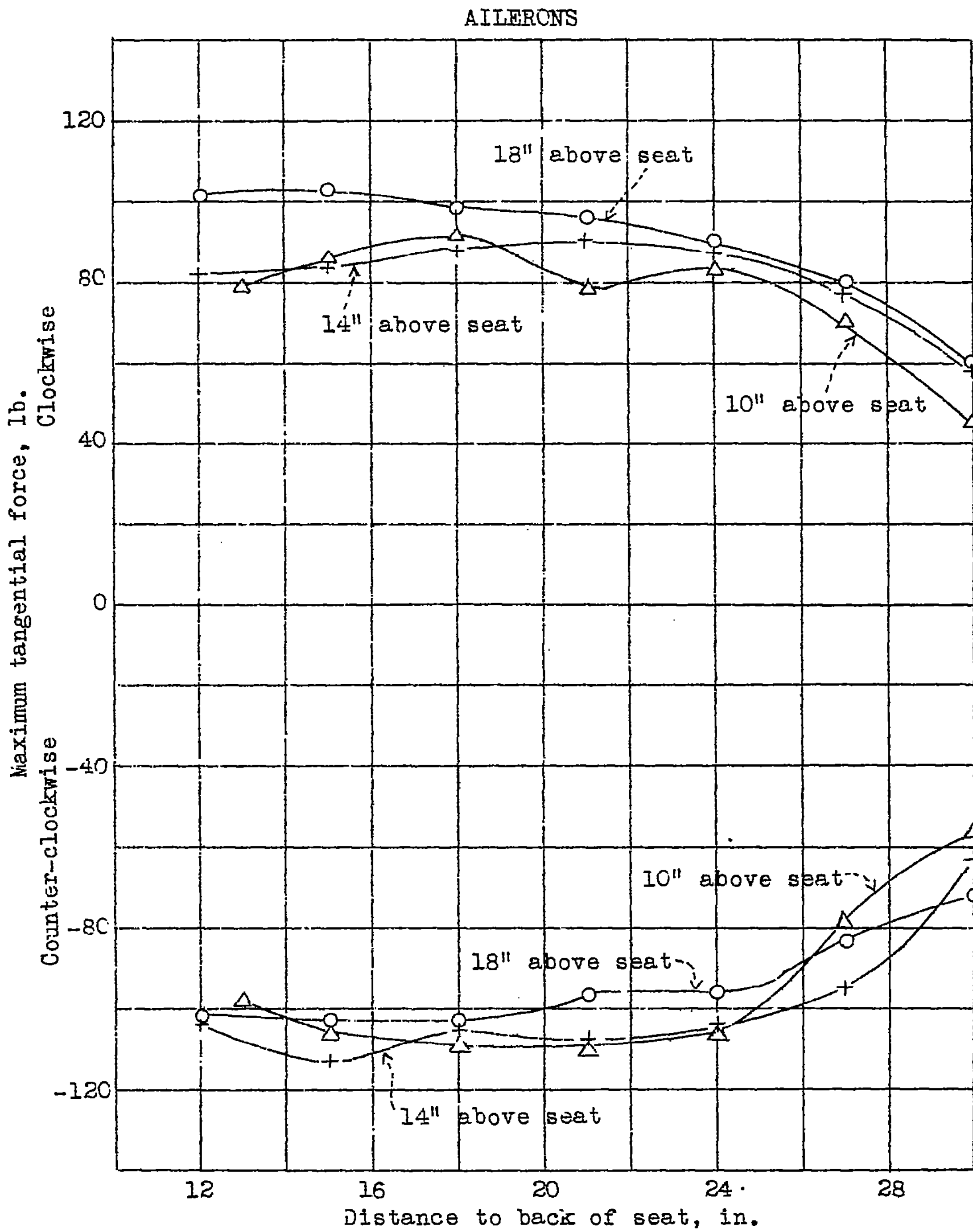


Figure 14.- Variation of tangential force with height of center of 12 inch wheel above seat, pilot secure, grip normal, pilot A.

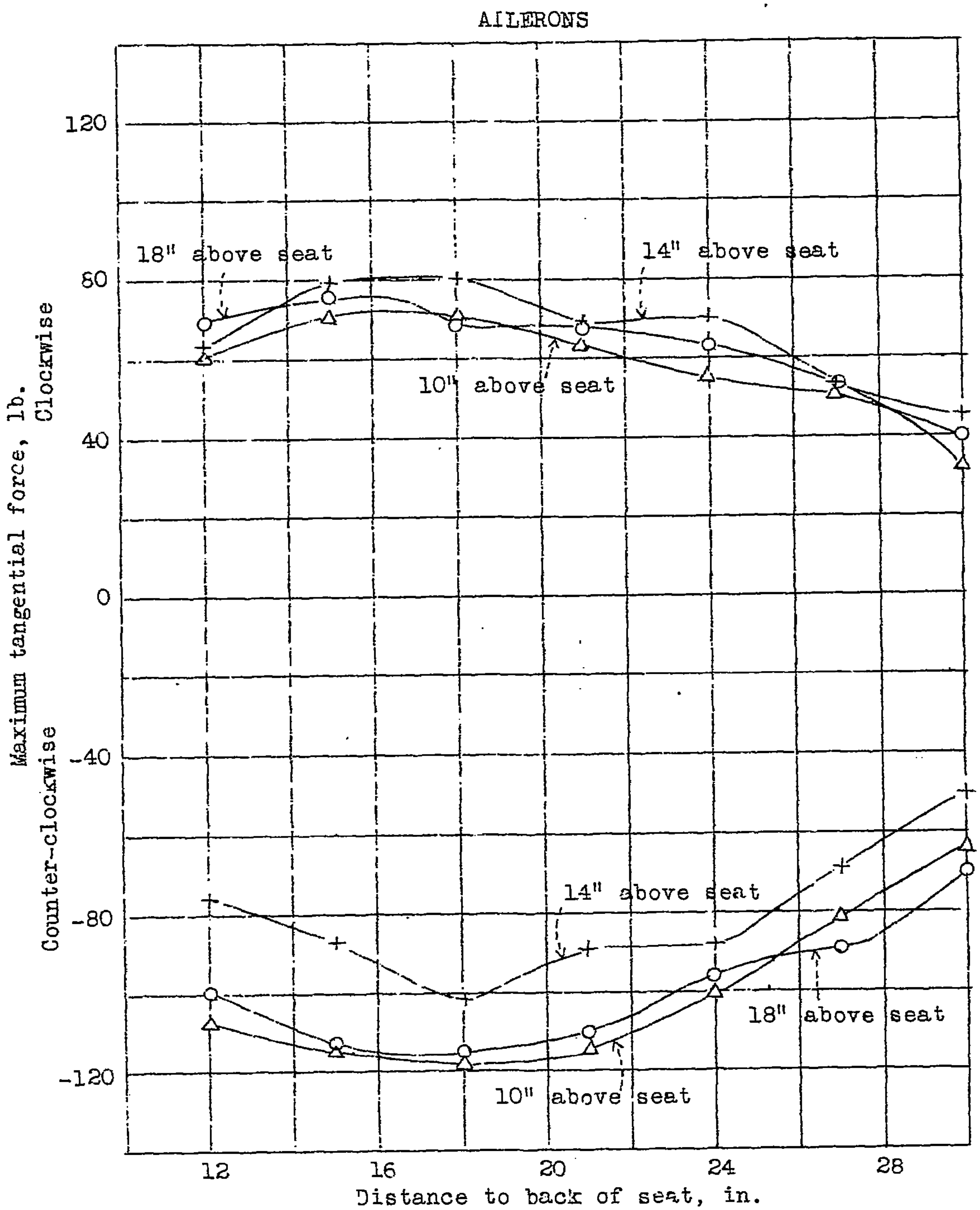


Figure 15.- Variation of tangential force with height of center of 12 inch wheel above seat, pilot secure, grip normal, pilot B.

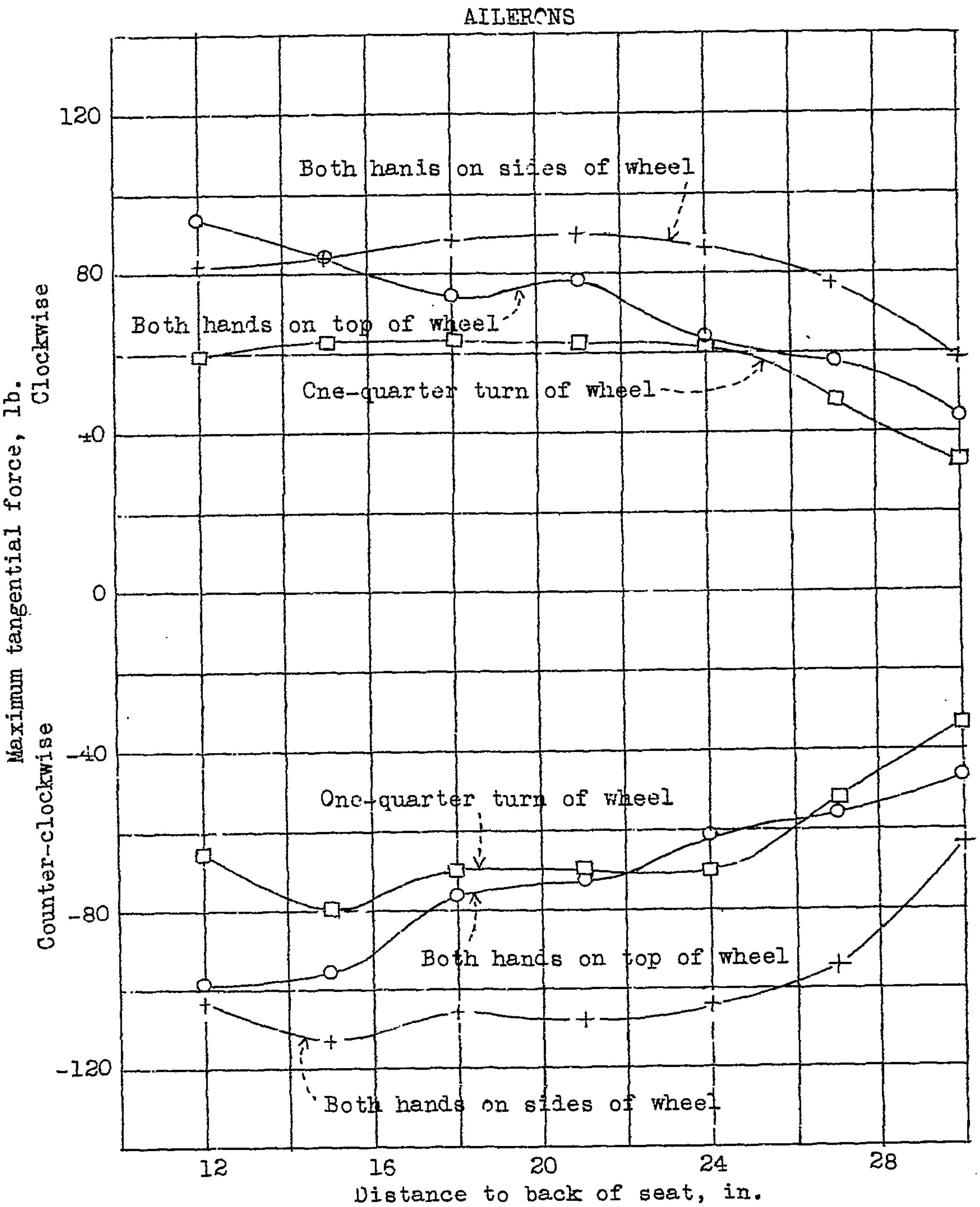


Figure 16.- Variation of tangential force with various two-hand grips, 12 inch wheel, center of wheel 14 inches above seat, pilot secure, pilot A.

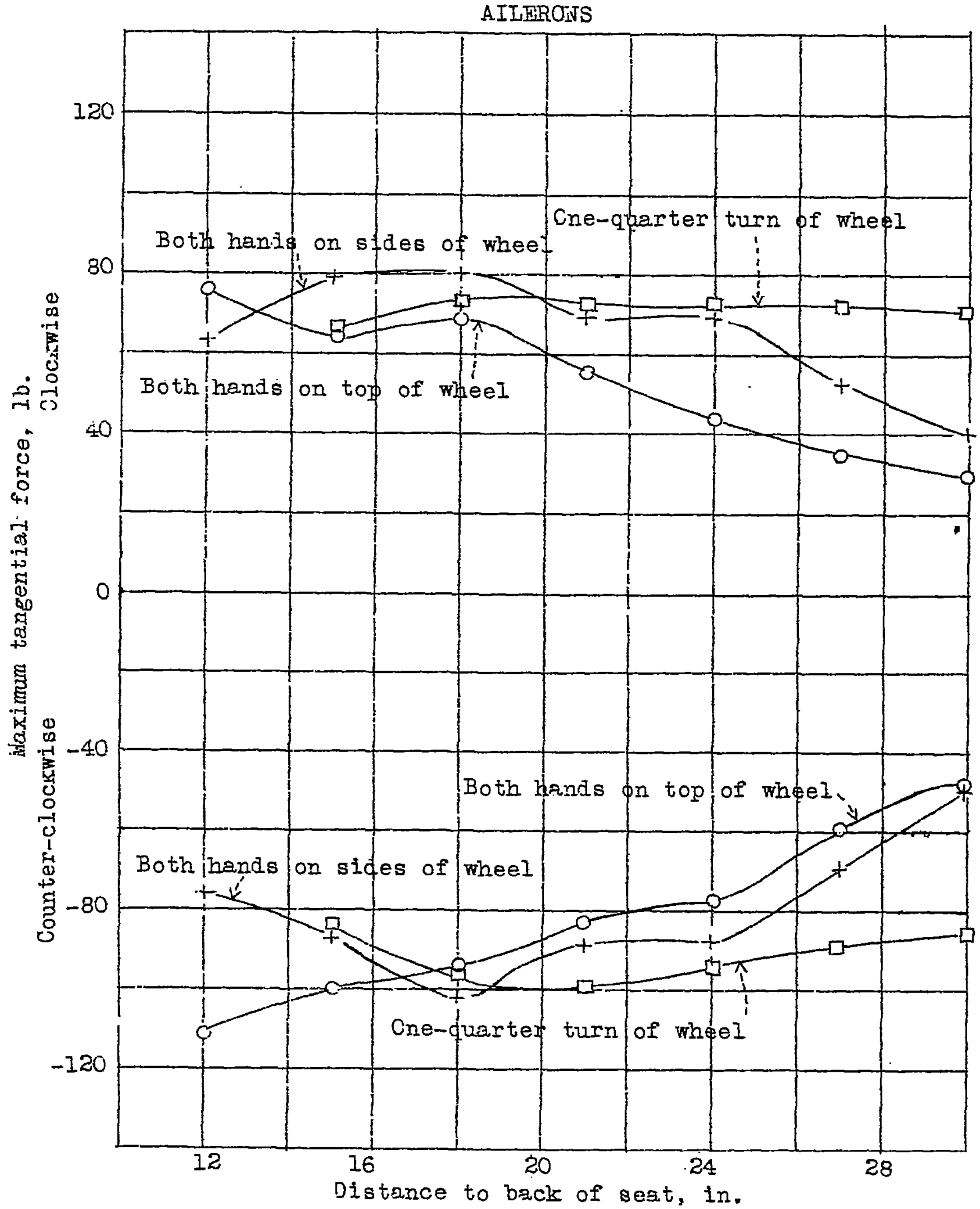


Figure 17.- Variation of tangential force with various two-hand grips, 12 inch wheel, center of wheel 14 inches above seat, pilot secure, pilot B.

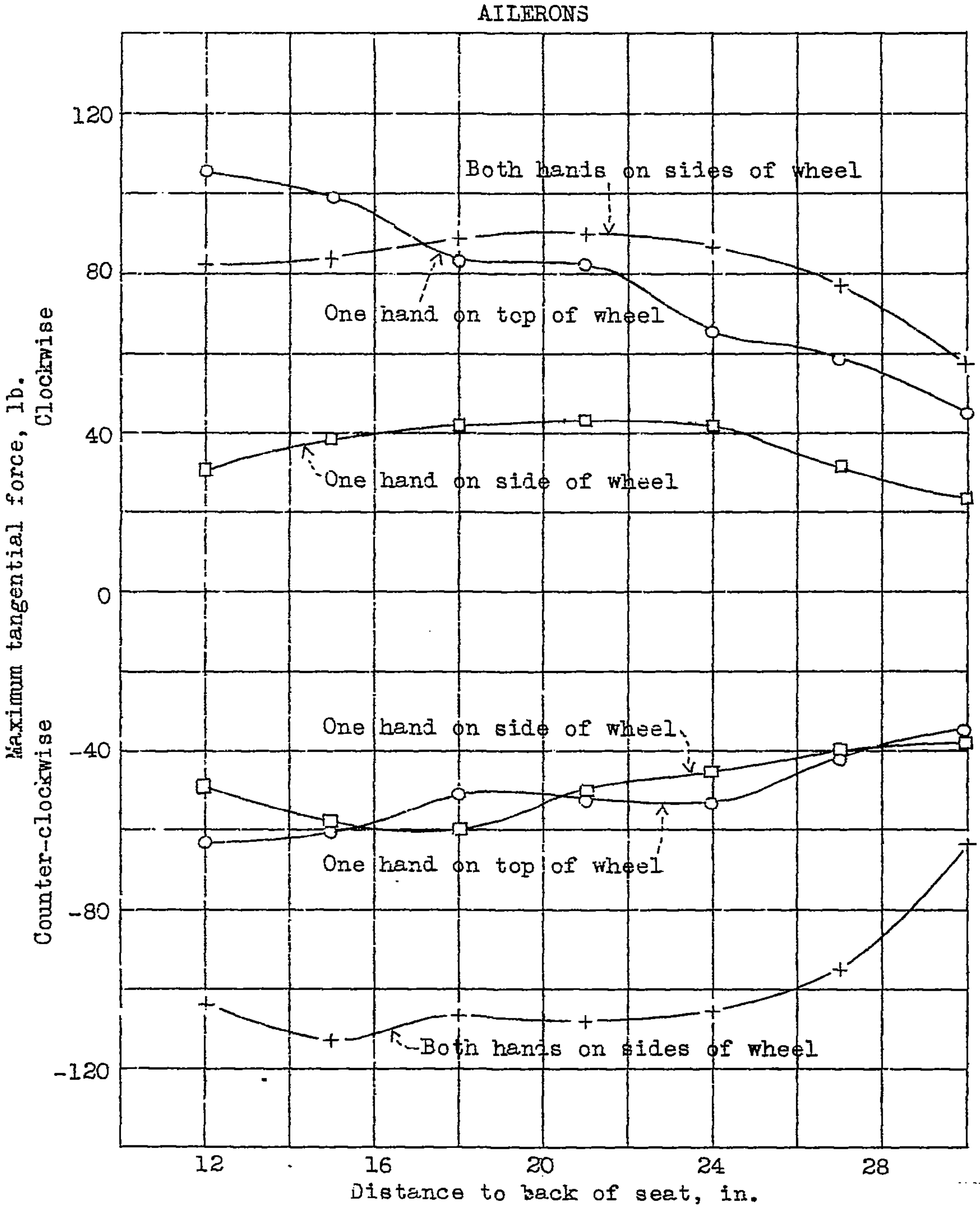


Figure 18.- Variation of tangential force with one hand (right) in two positions on wheel, with both hands, grip normal, 12 inch wheel, center of wheel 14 inches above seat, pilot secure, pilot A.

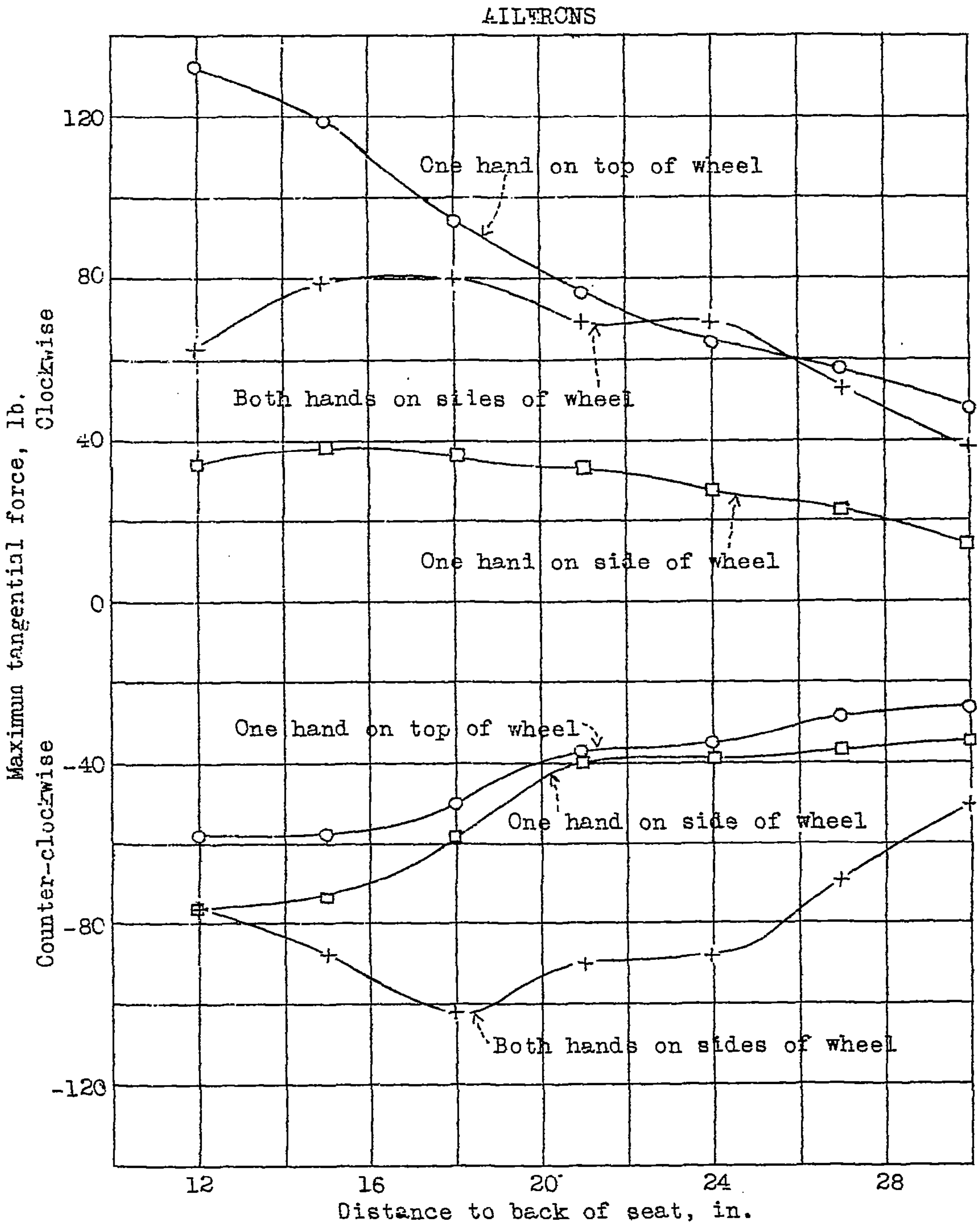


Figure 19.- Variation of tangential force with one hand (right) in two positions on wheel, with both hands, grip normal, 12 inch wheel. center of wheel 14 inches above seat, pilot secure, pilot B.